

## OPERATIONALLY RESPONSIVE TACTICAL MICROSATELLITES

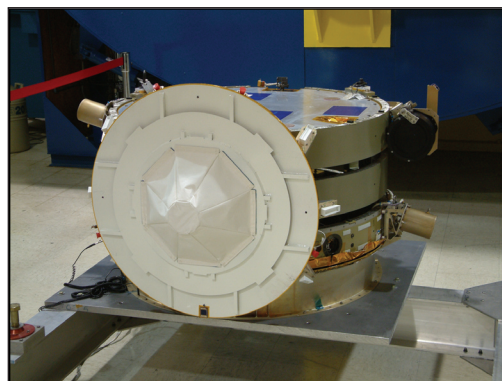
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**Introduction:** The Secretary of Defense's Office of Force Transformation (OFT) and the Naval Research Laboratory, in concert with the Air Force Research Laboratory (AFRL), are expanding their development of and experimentation with operationally responsive tactical microsatellite systems. Key elements of this system include: modular payloads, a highly automated satellite bus, common payload and launcher interfaces, launch on demand, and direct tasking and data dissemination using the Secret Internet Protocol Routing Network (SIPRNET). This system ultimately integrates space assets into the forces so that the Joint Task Force (JTF) Commander can call up assets by deciding the payload capability required, the area of interest, the area for direct downlink, and the date the assets must be operational. This article provides an overview of this experimentation, and a roadmap for where operationally responsive space is going.

**Background:** The Naval Research Laboratory (NRL), in concert with OFT, developed a tactical space system concept that makes space an organic part of the JTF. Three enabling elements of this system are capable microsatellites, low cost and rapid launch systems, and tactical networks, primarily the SIPRNET. Based on this work, OFT started the Operationally Responsive Space Initiative consisting of a series of experiments. TacSat-1 was the first experiment in this initiative.

During the second half of 2003 and the first half of 2004, NRL designed, assembled, integrated, and tested the TacSat-1 spacecraft. The entire spacecraft was completed in less than one year, from go-ahead to the end of system-level testing, for less than \$10M. This spacecraft (Fig. 3) is currently awaiting launch on the maiden flight of the Space Exploration Technologies (SpaceX) Falcon I launch vehicle. The second experiment in this initiative, TacSat-2 (Fig. 4), aims to build on this achievement, and continue to develop near-term paths for the tactical exploitation of space. These efforts have helped to create and institutionalize a joint TacSat experimentation program with the objective of testing key elements needed to realize a fully operational system. TacSat-3 was the first experiment selected under this joint process. TacSat-4 is already in the planning stages, with a possible selection in February 2005.

**Objectives:** The overall objective of the TacSat experiments is to test the key elements needed to realize an operationally responsive space system. Integral to the TacSat approach is operational experimentation, which closely couples the science and technology (S&T) and research and development (R&D) work with realistic field evaluations and concept of operations (CONOP) development.

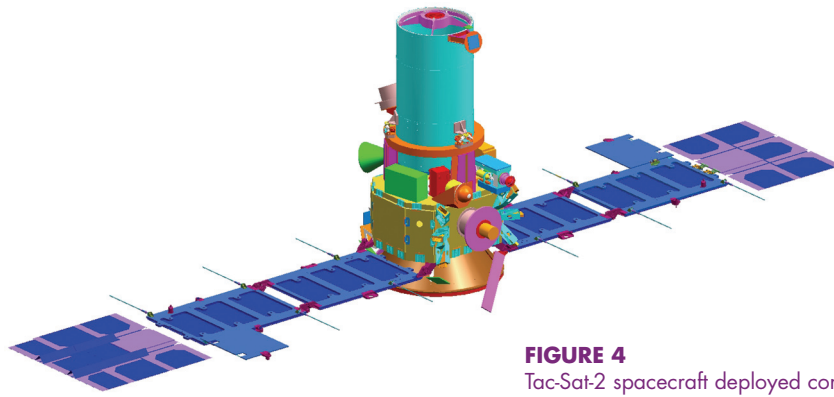


**FIGURE 3**  
TacSat-1 spacecraft after vibration testing.

**TacSat-1:** The primary objectives of TacSat-1 are: to provide an operationally relevant 100 kg class microsatellite with electronic intelligence (ELINT), specific emitter identifier (SEI), and cross-platform capability; demonstrate launch within one year (which was not met), while supporting a new low-cost commercial launch vehicle; make the space asset an organic part of the forces; and develop lessons learned and process to begin a repeatable cycle. Spacecraft development and launch are to be completed for less than \$15M. The success to date of this experiment has helped OFT successfully excite the broader DoD and industry in the responsive space area. With an eye toward an operational system, TacSat-1 contributes SIPRNET-based networking using the Virtual Mission Operation Center (VMOC) software, support for a new low-cost launch vehicle, and an iterative operational experimentation approach led by PACOM.

**TacSat-2:** TacSat-2 begins a spiral development cycle. One objective of the TacSat-2 experiment is to develop an understanding of the requirements for and limitations of rapid deployment. This includes launch vehicle integration, launch, and on-orbit checkout of the satellite. A second objective is to understand the requirements and limitations for the rapid development of new spacecraft and payloads. From an operational standpoint, the program seeks to obtain high-resolution images of tactical significance using

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**FIGURE 4**  
TacSat-2 spacecraft deployed configuration.

the VMOC operational network to task the satellite and disseminate the resulting data. Another objective is to develop and test a CONOP for the geolocation and cued imaging of a target during the same pass. TacSat-2 also will experiment with autonomous flight software to perform on-orbit checkout of the spacecraft, and autonomous tasking of the various payloads carried by the spacecraft. The most important contribution of TacSat-2 is the use of a space-based common data link (CDL) tactical communications link. Flying a CDL transponder requires ground-breaking work in frequency allocations and communications security (COMSEC) approaches.

**TacSat-2 Payload Capabilities:** The TacSat-2 spacecraft carries a large number of experimental payloads. The payloads that primarily address operationally relevant tactical capabilities include the Target Indicator Experiment (TIE) supplied by NRL and the imaging system supplied by Nova Biomimetics and SAIC. The TIE payload is an improved version of the primary payload carried by TacSat-1. The TIE payload performs real-time signal geolocation and SEI of radio frequency (RF) signals using space and air-based collection platforms. It is also capable of collecting the Automated Identification System (AIS) signal now required on large ships for port safety and homeland defense. The TIE payload is also reprogrammable on-orbit for acquiring new targets.

The TacSat-2 imaging system has panchromatic, red, green, and blue sensors with a ground sample distance (GSD) of approximately 1 meter. This imager uses a Fairchild Imaging CCD 583 TDI Line Scan array, sampling at approximately 9600 lines per second. The high ground scan speeds of TacSat-2 that result from its low Earth orbit (~7.5 km/s satellite ground trace speed) are an ideal application for a time-delay integration (TDI) approach. The TDI process is essentially noise-free, allows charge accumulation to take place over the number of TDI stages, and pre-

serves the ground resolution capability of the very high rates that the TDI lines are “scanned” off the array.

**TacSat-3, -4 and Beyond:** While efforts on TacSat-3 and TacSat-4 have just begun, the primary objective of both of these experiments will be to identify and mature the standards (interfaces, performance levels, etc.) necessary to develop a standard spacecraft bus in the near term. A successful standard bus has been elusive in the past. However, by coupling elegant and discipline standards for system interfaces with realistic acquisition goals, a standard microsatellite class bus is achievable. This prototype work is focused on transitioning the design to the Space and Missile Systems Center (SMC) for acquisition. Combining SMC operationally responsive space procurements of a standard bus with SMC procurements for STP will provide the necessary incentive for payload developers to keep their payloads within the limits of the standard bus’ capabilities.

**Key Partnerships:** Many successful partnerships made TacSat-1 possible. As the TacSat series progresses, many more partnerships will develop. The primary programmatic partners for TacSat-1 are OFT, NRL, SpaceX, and SMC. For TacSat-2, NRL and AFRL have teamed up with an AFRL lead industry team. Both TacSat-1 and TacSat-2 payload capabilities have been possible because of the diverse capabilities within NRL. Code 8100 has provided an ELINT payload with cross-platform (spacecraft to aircraft) capability, Code 5700 provided the SEI capability and IR camera, Code 7200 provided imaging expertise and radiometric calibration of two commercial cameras, and Code 8200 provided the spacecraft engineering for integration and testing; Code 8100’s Blossom Point facility will be the ground station for flight operations. As the TacSat experimentation process formalizes, partnerships are expected to grow with Air Force Space Command, Space and Missile Systems

Center, Air Force Research Laboratory, Army Space and Missile Command, and the Marine Corps space requirements representative.

## HEATING OF THE POLAR IONOSPHERE

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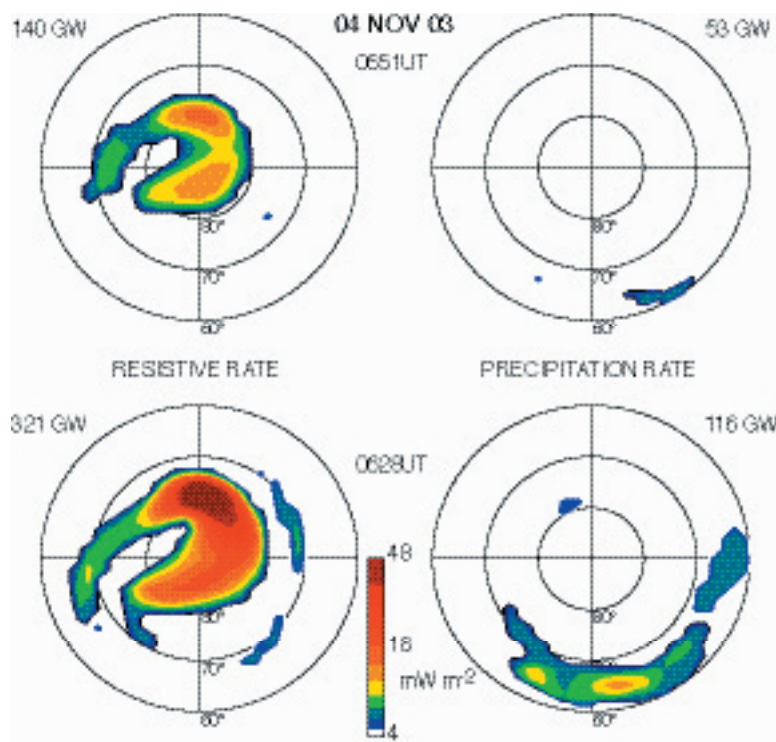
**Introduction:** As technology advances, modern society and especially the military rely on space-based assets. Sensitive systems include communications, surveillance, and navigation. Consequently, understanding and predicting “space weather”—the state of the environment in near-Earth regions—has become increasingly critical.

Recently, geomagnetic storms have come to the public’s attention through the popular press. For example, the great storms that occurred around Halloween in 2003 were widely reported in the news. Adverse effects resulting from the impact of geomagnetic storms include the loss of satellite services because of electronic disruption and outages in the electric power grids from surges. In this article, we discuss research on another consequence of geomagnetic activity, namely, the large amount of energy deposited in the polar ionosphere. During geomagnetic storms, the heated ionosphere and neutral atmosphere expand, increasing density at high altitudes so that satellites experience enhanced drag. As a direct result, orbits are altered, communications

to other satellites or to the ground can be disrupted, and the spacecraft may require a “boost” to continue its mission.

**Background:** The source of the energy responsible for heating the ionosphere and atmosphere is the Sun. Normally, solar radiation is the primary contributor. However, during solar disturbances, the solar wind plays an increasingly important role. The solar wind is a plasma that continually streams radially away from the Sun. The solar wind also carries a magnetic field called the Interplanetary Magnetic Field (IMF). During solar storms, the solar wind is greatly enhanced, with the density and IMF strength many times the nominal values. These solar storm events can last more than a day and are often associated with the occurrence of a coronal mass ejection (CME) on the Sun. This was the case for the 2003 Halloween storms. When the direction of the disturbed IMF as it reaches the Earth is opposite to the direction of the Earth’s magnetic field, a geomagnetic storm occurs, and the solar wind energy flowing into the magnetosphere and downward to the ionosphere is greatly enhanced. In recent years, considerable effort at NRL and other research institutions has been devoted to studying and predicting these conditions and their effects.

Two main processes deposit solar wind energy in the polar ionosphere: resistive heating and energetic particle precipitation. Electric currents are driven by



**FIGURE 5**  
Polar plots of contours of resistive and precipitation heating for the southern hemisphere on 04 November 2003. The top row shows heating approximately 6 min before a solar wind shock wave arrives. The bottom row is taken about 6 min after arrival.